MODELING THERMAL MODEL OF A DISK COIL WITH DIRECTED OIL FLOW USING MATLAB SOFTWARE

NUR DARINA BINTI AHMAD

A thesis submitted in partial fulfillment of the requirement for the award of the Degree of Master of Electrical Engineering

Faculty of Electric and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

JULY, 2012

Special Dedication To:

Both beloved parents,
Hj. Ahmad bin Said & Hjh. Nazimah binti M. Khalid

Helpful siblings,
Jasmin Ilyani & family, Lidyawati Izzaidah & family, Intan Radina and Siti Fatimah

Learned advisor and guider,
Dr. Mohd Taufiq bin Ishak

Last but not least, my fellow friends in UTHM for continuous ideas and supports directly and indirectly in completing this thesis.

ACKNOWLEDGEMENT

As life goes on I am starting to learn more and more about responsibility. And I realized that everything I do is affecting the people around me. By the way, every master by course student has a responsibility to do his Master Project as to accomplish the target in studying. This responsibility created such a beautiful memory and I keep thinking that my project will be useful to others. So, I want to take this time out to gratitude all of you who are involved in making this project a success.

Firstly, I would like to express my thankful to the 'King of The World', Allah. With His permission I could finished my project successfully as it become a part of my life seeing as I have been a master student.

I would like to take this opportunity to express my deepest gratitude to my supervisor, Dr. Mohd Taufiq bin Ishak who has persistently and determinedly assisted me during the whole course of this project. It would have been very difficult to complete this project without the enthusiastic support, insight and advise by him. In fact, no diamond or pearl could ever replace for the guidance that you have given to me.

My outmost thanks also goes to my family members who has given me support throughout my academic years and always stand by my side through the joy and the pain. Without them, I might not be the person I am today. It is to my advantage that I also acquired help and support from friends just like a flower needs rain.

Thank you.

ABSTRACT

Directed oil flow of a disk transformer in this model is guided by the oil flow washer. The model is established to investigate the temperature rise in the oil-filled transformer windings. Mass flow distribution and pressure drop concept are by using the number, size, location of horizontal ducts, fluid properties and the temperature variables. Pressure drop calculation is a temperature dependent and caused uniform heat distribution. An iterative solution is required to solve the equation to find the oil velocities, oil temperature and disk temperature. Because of the concept in every pass is the same, this model proposed to design in a single pass. The oil velocity and pressure at the last path can be used as input value to calculate the next pass. As disk temperature is very sensitive to the changes of the variables, so designing a suitable parameter for a single power transformer is very important. Matlab perform better in iterate equations and modeling disk transformer where the result is nearly accurate.

Keywords: disk transformer, thermal model, oil temperature rise, oil velocity, pressure, iterative solution

ABSTRAK

Di dalam model ini, pengaliran minyak dalam pengubah pengalir cakera dipandu oleh penghadang minyak. Model ini bertujuan untuk menyiasat kenaikan suhu dalam sesebuah pengubah yang berasaskan minyak. Konsep aliran pengagihan jisim dan kejatuhan tekanan diaplikasikan dengan berdasarkan kepada bilangan pengalir cakera, saiz, kedudukan laluan minyak yang mendatar, sifat bendalir pembolehubah suhu. Pengiraan kejatuhan tekanan bergantung kepada perubahan suhu dan menyebabkan pengagihan suhu secara seragam. Penyelesaian secara berulang-ulang diperlukan untuk mencari halaju minyak, suhu minyak dan suhu pengalir cakera. Disebabkan konsep kiraan untuk setiap bahagian dalam sesebuah pengubah adalah sama, model ini dibina dengan mengira dalam satu bahagian sahaja. Suhu pengalir cakera amat sensitif kepada perubahan sebarang pembolehubah, jadi merekabentuk pengubah yang bertepatan dengan parameter adalah penting. Disamping itu, perisian Matlab menunjukkan prestasi yang baik dalam melakukan penyelesaian berulang-ulang dan pemodelan pengubah cakera dimana hasilnya adalah hamper tepat.

Katakunci: pengubah cakera, model haba, peningkatan suhu minyak, halaju minyak, tekanan, penyelesaian berulang-ulang

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

IEC	-	International Electrotechnical Commission
IEEE	-	Institude of Electrical and Electronic Engineer

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

The history of transformer starts since 1880 and in year 1950, the first power transformer with 400kV was introduced in a high voltage electrical power system. In 1970's, the transformer was produced with large unit rating, 1100MVA. Meanwhile in1980, the rating is increase to 800kV and is still increasing today.

In electrical power system network, power transformers are used to step up the voltage at the sending side and then step down to the desired level. This is because the high voltage cannot be distributed to the end user [1]. A good oil power transformer can be operated up to 20 years but today there are a lot of power transformers that their life exceeds for more than 50 years. The extended of the life limit in power transformer relates to the insulation system that depends on the temperature. The cooling component also plays an important role in order to make power transformer perform well.

Theoretically, thermal model is a mathematical model that dynamically predicts the temperature of an object. The accuracy of the model is due the function of its algorithm and the accuracy of the value used for the object thermal capacitance, thermal resistance to its surroundings and heat generated in or removed from the object [2]. So in a power transformer thermal model it can be used to predict the temperature distribution; at the conductor and at the oil transformer [3].

Predicting temperature distribution is very important in a power transformer as it is very sensitive to temperature rise. A single incensement of the temperature above the standard limit can make a transformer life reduce by half [4]. Figure 1.1 shows a winding schematic diagram for a single transformer Figure 1.2 illustrates a simple 2D model that has been referred in this project in order to find its temperature distribution.

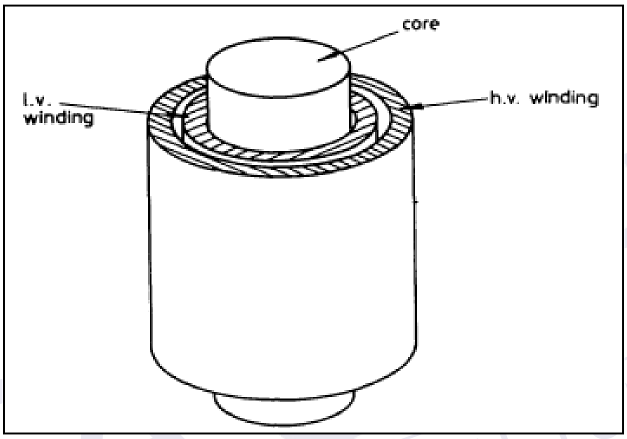

Figure 1.1: Winding schematic diagram for a single phase transformer.

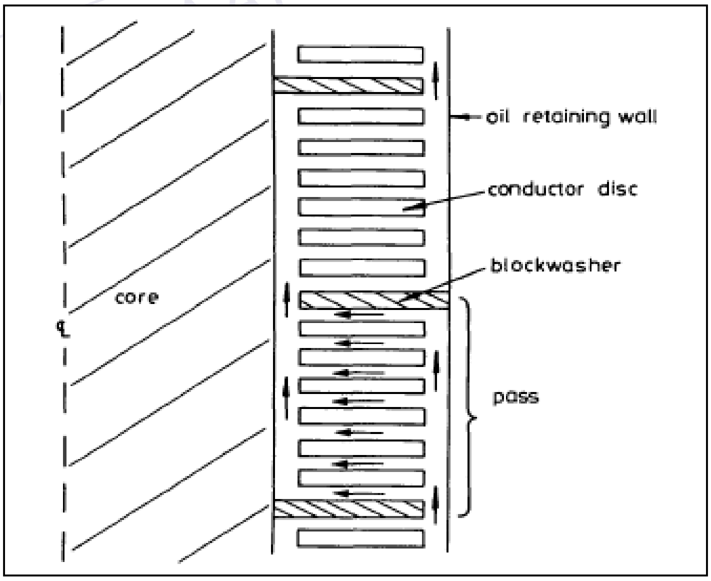

Figure 1.2: Flow path in winding- vertical section

Unfortunately, the ability of a transformer also depends on ambient condition such as temperature, wind and rain. For example, the transformer operation will become worst during the sunny day as the temperature increase. It will operate at the capacity limit but just monitoring internal and oil temperature. This problem become complicated when the temperature is not uniform inside the transformer and can damaged it due to local hot spot that happen. The oil temperature may become so hot that would sustain an electric arc and a transformer may explode under this condition.

1.2 Problem statement

In liquid-immersed power transformers, the temperature of the winding is very important in order to longer the term-of life of the transformer. Knowing the temperature distribution especially hot spot temperature at each point of transformer is very importance [1, 2, 4, 5, 6] in order to make it operate safety for a long period.

In Malaysia, most of the transformers that are used by Tenaga Nasional Berhad (TNB) use mineral oil as transformer insulating oil. The insulating oil temperature depends on the winding temperature and is usually used to indicate the operating conditions of the transformer [5]. The increase in temperature will influence the insulating material and may cause aging. Depends to the insulating material type, the transformer has a maximum limit of temperature rise [7].

There are a lot of numerical transformer protection relay available today including the protection function that operate on insulating oil temperatures, calculate loss of life due to high oil temperature, and predicted oil temperature due to load.

By the way in this project, software is used to predict the heat distribution in liquid-immersed transformers. There are various ways that can be used in modeling power transformer but some of them are complicated, so by choosing programming in Matlab life becomes easier. When comparing to other programming such as C, C++ and Fortan, Matlab programming is faster because there is no type of declaration needed, automatically handled memory allocation/de-allocation and functions and scripts can be access automatically from path.

1.3 Objectives

The objectives of this project are to:

(i) Investigate the temperature rise and oil velocity along each path segment in the transformer.

(ii) Develop a program that can modulate the suitable parameter that not exceeds maximum temperature rise in disk coil transformer; such as number of disk, oil pressure and velocities, oil nodal temperatures and path temperatures rise and disk temperatures.

(iii) Test the program by using different value in the parameter.

1.4 Scope

There are some limitations in this project to be considered:

(i) This model is limited to disk type winding and directed oil flow where the washer is used to guide oil flow through disk coil.

(ii) The design concept just consider 2D element not 3D (finite element) at the same time assumed conductor temperature is the average disk temperature.

(iii) Modeling and implement a transformer model using Matlab software.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

It is necessary to make some background studies on modeling and theories that are required in order to develop this project. So this chapter will focus more on the specification on this project such as power transformer, core and coil, cooling system, oil flow, and MATLAB software.

2.2 Power Transformer

Transformers are static electrical devices, involving no continuously moving parts and used in power electric system to transform voltage level between two circuits through the use of electromagnetic induction which is discovered by Faraday in 1831. Usually power transformer referred to those transformers rated at 500 kVA and above and located between generators and the distribution circuit [3], see Figure 2.1. Power transformer is used in a system that consists of a large number of generation location, distribution point and interconnection within system. At the generator side, power transformer used for step-up operation and known as generator step-up transformer (GSU) [6]. Mean while, step-down transformer used at distribution side. Power transformers are available at single phase and three phases.

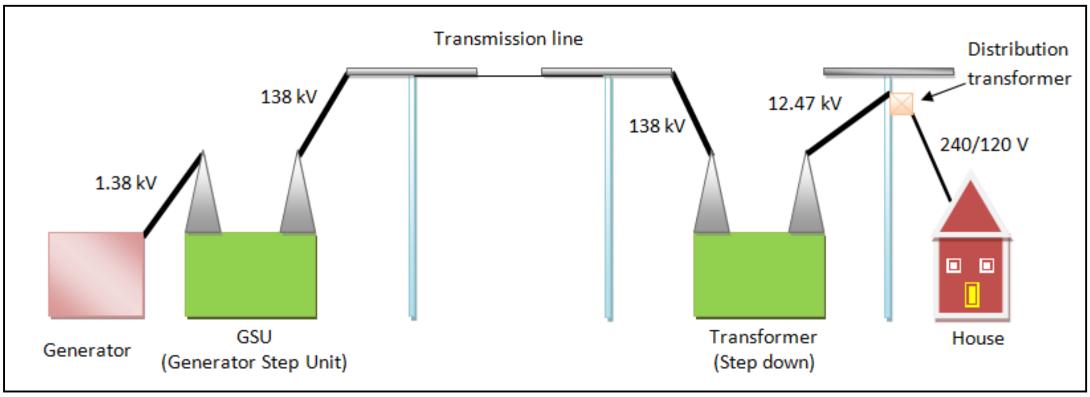

Figure 2.1: Schematic drawing of a power system.

A laminated steel core with copper or aluminum windings are used in power transformer in which the windings have a solid insulation of refined paper and a high quality of mineral oil as insulating and cooling medium for entire transformer. The core, windings and insulation that used all have specific thermal capabilities. Losses in the core and windings can cause temperature rise in the transformer which will transfer to insulating oil. This will effect transformer capabilities and usually caused premature failure. Figure 2.2 represent a simple transformer design nowadays.

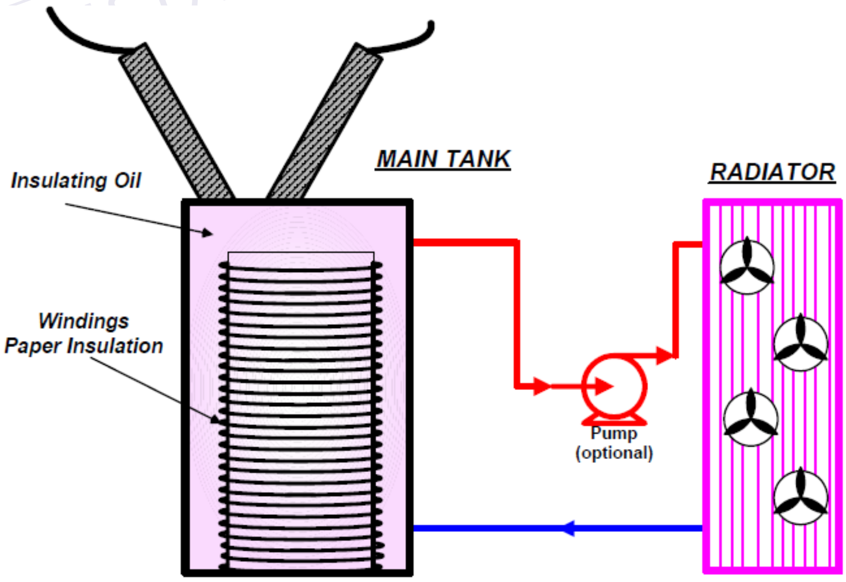

Figure 2.2: A simple transformer representation

2.2.1 Liquid-filled transformer

Each of the transformers are constructed according to its application. Indoor transformer intended to use dry type transformer but sometimes can be liquid-filled. But for outdoor use, usually liquid-filled transformers will be chosen. Some of the dry type transformers are not suitable for outdoor because the method of cooling system is by circulating air through the coil and core assembly which is use either by force air flow (fan) or natural convection.

This cooling method is suitable for low voltage - indoor transformer. At higher voltage, oil is needed to insulate the winding due to the losses which are high through the process of conduction, convection and radiation. For effective winding cooling, the moving oil must be able to contact with every conductor for maximum convection and conduction of the conductor heat from the winding to the oil. In the other hand, direct air cooling is not effective for outdoor environment where it can make the windings dirt and moisture.

A Comparison of Liquid-Filled and Dry Type Transformer Technologies written by Tommy Nunn [7] of IEEE-IAS Cement Industry Committee evaluated the comparison both types of the transformers. He stated that both type have pro and cont in terms of loads, environment, purchase cost, safety, availability to operate, materials and manufacturing process. In recent years, transformers technologies have improved especially in less flammable and environmentally friendly fluids in liquid-filled transformers. In dry type transformer, vacuum technology has been introduced to improve the insulation system, core material and computer design programs.

Another research has been done by Jeffery Wimmer, M. R. Tanner, Tommy Nunn and Joel Kern on the specification Installation and operational impact of both types in a marine environment [8]. They found that fiber glass winding will have maximum operating size through 25000kVA and also application of vacuum technologies increased the reliability on tap changing reduced the maintenance. Table 2.1 list some advantage and disadvantage of liquid-immersed transformers.

Table 2.1: Liquid-filled transformer

Advantage	Disadvantage
Transformer oil is combustible	Needs oil regular checking filtration and replacement of oil
Smaller size	Costly and need high recurring expense
Lower cost	Produce a little bit of danger
Greater overload capability	Located away from the main building

2.2.2 Circular core design

Circular core and coil winding usually does not provide complete circulation of oil to every conductor and every layer of windings. Even the circular layer windings still have significant quantities of windings insulation though the space factor in the core and coils are an improvement [11]. Figure 2.3 shows an example of circular core and coil winding assembly utilizing layer windings.

Figure 2.3: Circular core and coil winding

The winding constructed of rectangular magnet wire with radial cooling spacer inserted between multiples of layers. By referring to Figure 2.5, the winding conductors were support by vertical rib and allow oil flow vertically for winding cooling. The circulating oil might contact around 60% of the conductors [11]. There is no radial spacer allowing oil to contact with the conductors between turns.

Basically concentric coils are wound over cylinders with spacer attached as to form a duct between conductors and cylinders. The flow of liquid/oil can be based solely on natural convection or controlled through the use of strategically placed barriers within the winding [11].

2.2.2.1 Disk winding

There are several types of windings such as pancake windings, layer (Barrel) windings, helical windings and disk windings. A disk winding can be built from a single strand or several strands of insulated conductors wound in a series of parallel disk in horizontal orientation with the disk connected either at inside or outside as a crossover point. Each disk consists of multiple turns wound over other turn with the crossover (inside and outside). Figure 2.4 shows the basic concept and Figure 2.5 outlines typical crossovers during the winding process [3].

Disk type windings are widely used in 25kV class and above. As its operation and test involve in high voltages, a particular attention is needed to avoid high stress between disk and turns near the end of the winding when voltage surge occur. A lot of techniques have been implemented to ensure an acceptable voltage distribution along the winding under these conditions [3].

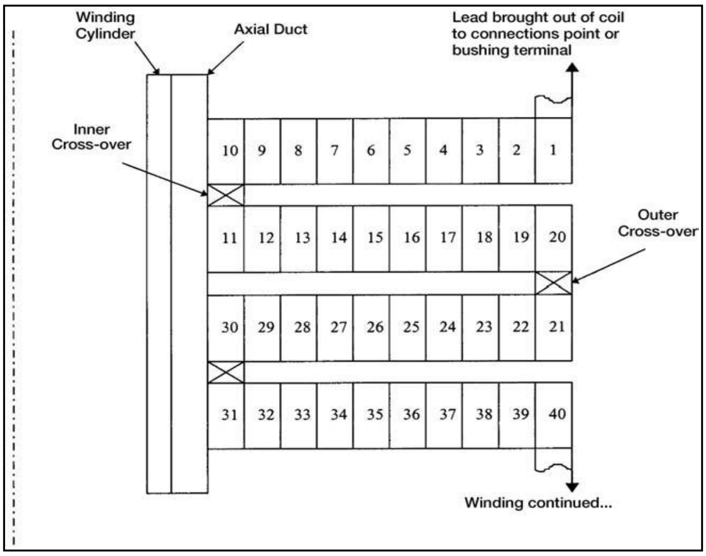

Figure 2.4: Basic disk winding layout

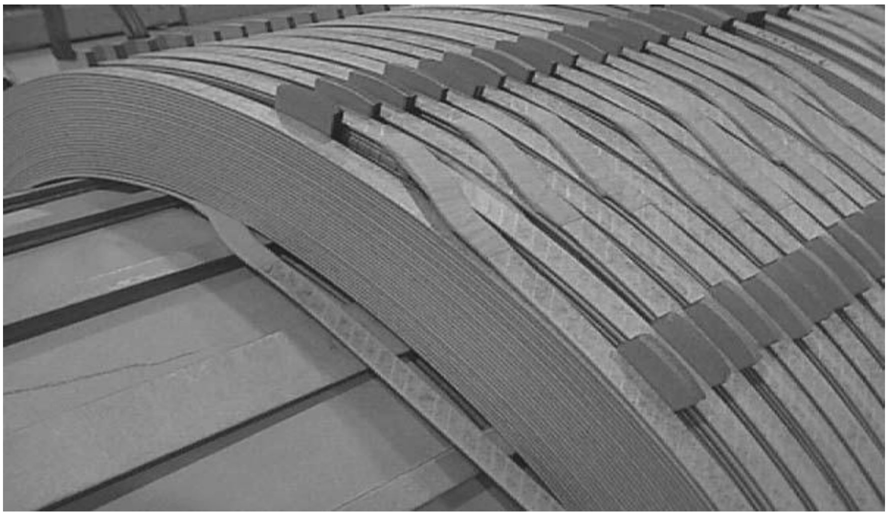

Figure 2.5: Disk winding inner and outer crossovers.

2.2.3 Directed oil flow

There are two types of oil flow in liquid-immersed transformer; directed and non-directed oil flow. Sometimes directed oil flow concept also known as guided liquid flow. Figure 2.6 and 2.7 represent windings arrangement comparing non-directed and directed flow. In non-directed flow transformers, the pumped oil flows freely through the tank. Meanwhile, in directed oil flows, oil washer is used at the top and bottom of a pass to induce a zig-zag cooling in the winding of the transformer as illustrated in Figure 2.8.

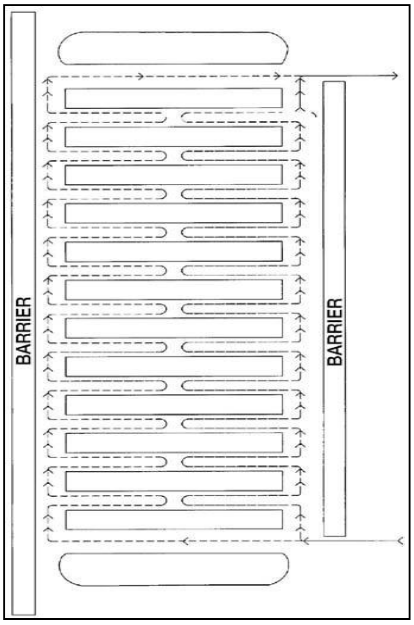

Figure 2.6: Non-directed flow

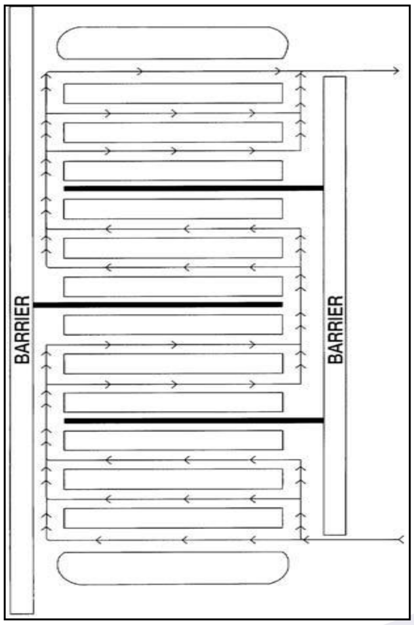

Figure 2.7: Directed flow

The oil is forced to enter from one vertical channel and exit from the opposite vertical channel [4], [9]. From the findings, oil velocity affects the recirculation zone where recirculation zone is proportional to the increased oil velocity and efficiency, the insulating oil as a cooling medium will drop. In the other hand, N. El. Wakil [10] et al. had investigated the fluid flow in power transformer and found that directed flow can give better result in reducing the temperature.

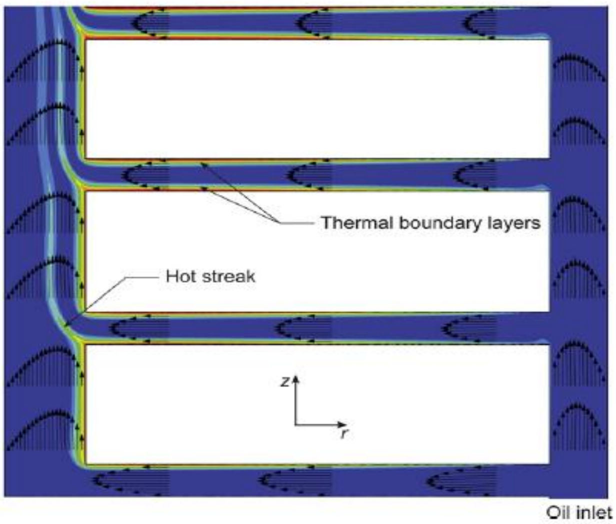

Figure 2.8: The effect heat transfer coefficient along the vertical disk. [4]

REFERENCES

1. S.H. Digby H. J. Sim, "Transformer design for dual voltage application," in *IEEE, Rural Electric Power Conference*, 2002.
2. A. Bulucea, L. Perescu M. C. Popescu, "Improved transformer thermal model," in *WSEAS Transaction on Heat and Mass Transfer*, 2009, pp. Vol. 4, No. 4.
3. M. Lehtonen, H. Nordman D. Susa, "Dynamic thermal modeling of power transformers," in *IEEE, Transaction on Power Delivery*, 2005, pp. Vol. 20, No.1.
4. M. Chaaban, P.Picher F. Torriano, "Numerical study of parameters affecting the tempeature distribution in a disc type winding," 2010.
5. L. Michael. Giordano Rich Hunt, "Thermal overload potection of power transformers - operating theory and practical experience," , Atlanta, Georgia, 2005.
6. B. Poulin [et al], *Transformer design principles with application to core-form power transformer*.: CRC Press, 2010.
7. T. Nuun, "A comparison of liquid-filled and dry-type transformers," , 2000.
8. M.R.Tanner, T. Nuun, J.Kern J. Wimmer, "Dry type vs. liquid immersed transformers: Specification installation and operational impact in a marine environment," in *Petroleum and Chemical Industry Conference (PCIC), 2011 Record of Conference Papers Industry Applications Society 58th Annual IEEE*, 2011, pp. 1-8.
9. W. Wu, S. Tenbohlen, Z. Wang A. Weinlader, "Prediction of the oil flow distribution in oil-immersed transformer windings by network modeling and computational fluid dynamic," vol. 6, no. 2, 2011.
10. N. C. Chereches, J. Padet N. El. Wakil, "Numerical study of heat transfer and fluid flow in a power transformer," 2005.
11. "IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformer," New York, 2010.
13. T. R Rao, A. Jain, M. Ramamoorty Haritha V. V. S. S, "Thermal modeling of

electrical utility transformer using finite element modeling technique and thermal-electrical analogy," , 2009.

14. M. S. Sorgic Z. R. Radakovic, "Basics of detailed thermal-hydraulic model for thermal design of oil power transformers," , 2010.
15. A.J. Oliver, "Estimation of transformer winding temperatures and coolant flows using a general network method," 1980.
16. E. P. Childs, "Flow maldistribution in disc-type power transformer windings," in *The 24th National Heat Transfer Conference and Exhibition*, Pittsburgh, 1987, pp. 137-143.
17. X. Li J. Zhang, "Oil cooling for disk-type transformer windings - Part I: Theory and model development," in *IEEE Transaction On Power Delivery*, 2006.
18. X. Li, M. Vance, J.Zhang, "Experiments and modeling of heat transfer in oil transformer winding with zigzag cooling ducts," , Canada, 2007.
19. L. W. Pierce, "An investigation of the thermal performance of an oil filled transformer winding," in *IEEE Transaction On Power Delivery*, 1992.
20. R. Pratap, *Getting start with MATLAB 7 - A quick introduction for scientists and engineers*.: Oxford University Press, Inc, 2006.
21. R. M. Del Vecchio and P. Feghali, "Thermal model of a disk coil with directed oil flow," in *IEEE, Transmission and Distribution Conference*, 1999, pp. 914-919.
22. X. Li, J. Zhang, "Coolant flow distribution and pressure loss in ONAN transformer windings - Part I: Theory and model development," vol. 19, no. No. 1, 2004.